New Possibilities for a Light Gluino

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Abstract

Despite many positive indirect indications of light gluinos direct searches for the expected signatures of gluino containing hadrons have so far turned up negative severely restricting the allowable windows in gluino mass. After briefly reviewing the status, we discuss a possible new decay scenario that could have allowed light gluinos to evade direct detection with possible consequences for other measurements.

1 Introduction

Recently several counter-indications to light gluinos have severely eroded the attractiveness of the light gluino scenario. These are primarily
1. New analyses of the running of the strong fine structure constant show consistency with standard QCD.
2. Direct searches for gluino containing bound states at Fermilab have turned up negative (KTeV and E761).
3. Concomitant predictions , in the Minimal Supersymmetric Standard Model (MSSM), of a light Higgs mass and a light chargino have been (at least marginally) ruled out at LEP II.

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Much theoretical and experimental effort could be spared if nature would respect the current majority opinion that light gluinos are now excluded. However, in the current paper we show how a modified light gluino scenario might be viable in spite of these negative results. There are still hints from several experiments that provide motivation for further consideration of light gluinos. The discussion here is organized as follows. In section II we discuss the above counter-indications to a light gluino and some of the proposed positive indications. In section III we discuss a new scenario for light gluino decay systematics, based on the idea of gauge mediated supersymmetry breaking. This scenario could loosen the constraints from the negative direct searches. In section IV we discuss some possible experimental tests at LEP II and elsewhere.

2 Indications and Counter-Indications

It has been known from the early days of Supersymmetry (SUSY) to the present [1, 2] that a very light gluino is a viable and theoretically attractive scenario. In addition, in the current decade, positive (though weak and indirect) indications for such a light color-octet fermion have emerged [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. Although some of these require additional (not unreasonable) assumptions such as flavor violating gluino couplings or squarks of a particular mass, and some of the experimental support for particular indications has eroded, sufficient reason remains to further explore the light gluino option.

Among the positive phenomenological indications of a light gluino that have been noted are the following many of which are due at least partially to the primary signature of a light gluino, an anomalously slow running of the strong coupling constant.

It is interesting to note that an earlier test [18] that reported negative results would have reached a positive conclusion if current measurements of $\alpha_s(M_Z)$ had been available. The QCD β function is now known up to three-loop order including gluino effects [19] so that the anomaly, if one exists, is very unlikely to be due to higher order QCD effects.

Analyses of data suggesting anomalously slow running have been done in the quarkonium region [7], from the quarkonium to the Z region [3, 8, 20], from deep-inelastic scattering [9], and in the Fermilab jet inclusive transverse

energy cross sections [15, 16]. However, some re-analyses of deep-inelastic data show consistency with the standard model [21, 22]. In general, the lower one believes the value of α_s is at low energies and the higher one believes its value is at high energies, the more likely one is to be interested in the light gluino option. If one is willing to rely on QCD in τ decay and on the current LEP measurements of $\alpha_s(M_Z)$, there is little room for a light gluino. However, the τ data is itself difficult to reconcile with quarkonium and other low energy data. One must either believe that the apparent value of $\alpha_s(M_\tau)$ is larger than the actual value due to some 10% contribution from non-perturbative corrections or that the width of the J/Ψ is reduced by some 90% due to relativistic effects.

If the τ data is misleading due to non-perturbative effects and the J/Ψ width gives a better estimate of the strong fine structure constant, one can also understand the narrowness of the ϕ [7] and then a light gluino is strongly favored. Further discussion of the low energy measurements of α_s and the "α_s problem" can be found in refs. [23, 24]. More recent measurements of the R parameter at $LEPII$ seem not to require a slower running but these are complicated by "radiative return" and W pair production and they are not yet accurate enough to rule out a light gluino. For instance, Delphi [25] reports

$$\frac{d\alpha_s^{-1}}{d\ln E_{cm}} = 1.39 \pm 0.34(stat) \pm 0.17(syst) \tag{2.1}$$

to be compared with expected values 1.27 in the standard model and 0.95 in the light gluino case. If the current LEP values of $\alpha_s(M_Z) \sim 0.123 \pm .005$ and the low values from quarkonia analysis are both correct then, not only is a light gluino strongly favored but, in addition, there must be some additional effect tending to increase the apparent value of $\alpha_s(M_Z)$. It has been shown [26] that this effect could be provided by virtual squark-gluino loops.

Concomitant predictions of the light gluino, within the gravity-mediated minimal supersymmetric standard model, are those of a light higgs and a light ($\mathcal{O}(M_W)$) chargino and neutralino, together with low $\tan\beta$ near 2. It could be considered encouraging that the indirect evidence from LEP also favors a light higgs but direct searches now, at least marginally, rule out these concomitant predictions. The light Higgs is now apparently above $90GeV$ and, in the light gluino scenario, the lightest chargino is experimentally at least $55GeV$ [27] to be compared with a maximum prediction of about $70GeV$ for

both the lightest chargino and the light Higgs in the MSSM light gluino case. Thus the light gluino is ruled out in the MSSM unless there are perturbations to these mass predictions or gaugino mass universality is broken.

Most recently, the CDF data on jet inclusive transverse energy cross sections and on the scaling ratio [28, 29] at two different beam energies have been shown to be in line with light gluino expectations. In addition, structure in the scaling function has the right features (dip then bump separated by a factor of 1.8/0.63 in X_T, with approximately the right height and width) to suggest the existence of valence squarks in the 106 to 133 GeV mass range [16, 30]. In the light gluino case such a relatively low mass squark would have evaded the Fermilab searches since it would decay into quark gluino without the standard high transverse energy lepton and missing energy signal. It should be noted, however, that $D0$ data, while consistent with a light gluino, do not confirm structure in the scaling ratio which would indicate the presence of a valence squark [31].

In contrast to these possible indirect hints of the existence of a light gluino, all direct searches have so far turned up negative. These have been based on the standard expectation that the light gluino would decay to quark-antiquark-photino through an intermediate squark with the approximate lifetime

$$\tau_{\tilde{g}} \sim \frac{m_{\tilde{Q}}^4}{\alpha \alpha_s {m_{\tilde{g}}}^5}. \tag{2.2}$$

A light gluino would be expected to hadronize into a gluino-gluino state (gluinoball), a gluino-gluon state (glueballino, R^0), a quark-antiquark-gluino state (mesino), or a three quark + gluino state (barino). The latter two types of gluino bound states would include new charged hadronic states for which there are stringent experimental limits. The gluinoball would decay rapidly and be virtually indistinguishable from a glueball state. There are in fact too many good glueball candidates to be explained by gluon composites only. However, there seems to be no reason why a large fraction of produced gluinos should not hadronize into glueballinos which do have a distinctive signature. One could theorize that mesinos and barinos are not formed for the same reason that there are no candidates for hybrid gluon containing

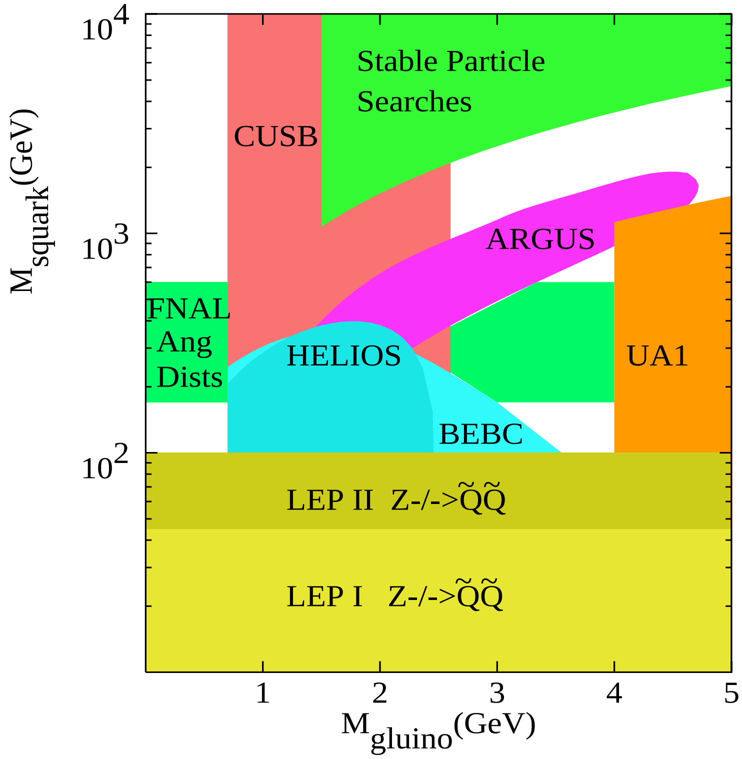

Figure 1: Current map of gluino windows. The regions ruled out by various considerations [35, 39, 40, 41, 42, 43, 44, 45] are indicated. Some of these such as the beam dump constraints and stable particle searches are dependent on the SUGRA-inspired relation between gluino lifetime and squark mass.

states ($qqqg$ or $q\bar{q}g$): The QCD potential is repulsive in the requisite color octet qqq or $q\bar{q}$ sub-state.

With the squark near or above the Z in mass the glueballino would be long-lived, depositing most of its energy in a hadronic calorimeter before decaying, and leaving only a small amount of energy to the missing photino. A produced gluino hadronizing into a glueballino would behave, therefore, very similarly to a normal gluon jet. This signature has been extensively reviewed [3, 32] and would allow a light gluino to avoid the missing energy trigger that puts a high lower limit on the mass of conventionally decaying SUSY partners.

However, the long lifetime of the glueballino makes it sensitive to other search techniques. The most stringent restriction on the R^0 state comes from the KTeV experiment [33] which convincingly rules out a long lived neutral particle with a lifetime up to 10^-8s contaminating a K_L beam and decaying into $\pi^+\pi^-+$ missing energy with the $\pi\pi$ state having joint invariant mass above the Kaon mass. In its current analysis KTeV requires such a high $\pi\pi$ mass to avoid background from CP violating K_L decays. One way out would be to have the photino mass so close to the glueballino mass that such a high mass hadronic final state would be kinematically excluded [34]. It seems likely that KTeV can also explore this possibility with later refinements in the analysis. A second way out would be to have the glueballino lifetime so long that it does not decay in the KTeV sensitive region. If such a glueballino were not much heavier than the nucleon, its decay could be confused with neutron inelastic collisions which limit the bounds set by stable particle searches such as [35]. Recently various authors have even considered an absolutely stable gluino [36, 37]. The consequent stable R^0 would have been evident in missing energy searches if its mass were greater than about $5GeV$ [37]. Below about $2GeV$ a stable R^0 cannot at present be conclusively ruled out since the signature knock-on events would not be distinguishable from neutron induced events for which the cross sections are poorly known. The viability of a stable R^0, of course, depends on such a particle not being able to bind to nuclei to create anomalous isotopes. The absence of such bound states might be understandable due to the inability of the flavor singlet glueballino to interact with nuclei via pion exchange (or even more massive meson exchange). The dominant interaction mechanism would be glueball exchange which is presumably too weak to lead to a thermally stable bound state. The same could not be said in the case of a stable

mesino or barino which would then lead to a great number of exotic anomalous isotopes. Such particles, therefore, are probably not phenomenologically viable. Further direct counter-indications come from the $E761$ experiment [38] which, however, would be voided if charged gluino containing hadrons are not bound due to the argument suggested above.

Perhaps the most constraining recent evidence concerning light gluinos comes from the dijet angular distributions measured at Fermilab and interpreted in terms of a squark decaying into a quark plus a light gluino [39, 40]. The absence of deviations from the standard model rules out, in the light gluino case, a valence squark between 150 and $650GeV$. In Tevatron run II it should be easily possible to extend this range above $1TeV$. If the predictions for scaling violations between the $2TeV$ and $1.8TeV$ data are not borne out [30] the window between $100GeV$ and $150GeV$ will also be closed. This would make the light gluino scenario very unattractive since squarks above a TeV would lead to extreme fine tuning problems for supersymmetry. In summary the constraints on gluino mass [35, 39, 40, 41, 42, 43, 44, 45] in the low energy windows in the current standard picture of gluino decay systematics are shown in Fig. 1. Earlier versions of this map can be found in references [46, 43]. In Fig. 1 we have updated the plot to include recent LEP and Fermilab constraints. The sloping lines in the constraints are based on the assumption that the gluino lifetime would be that of the Sugra-based model. In the next section we consider a gauge mediated model which would drastically change the relation between the gluino lifetime and squark mass.

3 Gauge Mediated Model

We turn now to a discussion of a new light gluino scenario, guided by the gauge mediated supersymmetry breaking (GMSB) ideas, which could avoid the problems presented by the negative direct searches while preserving the positive indications. It has been noted that there is an attractive scenario within the GMSB scheme in which the gluino is the lightest supersymmetric particle (LSP) or the next-to-lightest with an ultra-light gravitino being the LSP [36]. There is no natural lower limit in these scenarios to the gluino mass and, in the low energy window its mass must, in fact, be below about 5 GeV [37]. In the GMSB models, the gluino mass is often naturally decoupled from the chargino and neutralino masses so that the constraints

on the latter are easily avoided. Similarly, once the MSSM predictions on chargino mass are eliminated, the light gluino constraint on $\tan\beta$ is relaxed allowing for somewhat higher (but still low enough to be phenomenologically interesting) predictions for the Higgs mass. The experimental bounds on the Higgs mass are, in fact, also somewhat relaxed by the Higgs decay to two gluinos. The same results can also be obtained in any model giving up gaugino mass universality such as that considered by [47]. Consistent with this model, we tentatively propose that the light Higgs and gaugino masses are in the $100GeV$ region except for the gluino which is below (perhaps far below) $5GeV$. If the R^0 is absolutely stable, providing it does not bind to ordinary nuclei to create anomalous isotopes it is then invisible to current direct searches.

We would, however, like to consider the alternative in which the gluino decays into an ultra-light gravitino and a gluon, the standard GMSB decay mode. The gravitino couples to the supercurrent with a strength, F,

$$\mathcal{L} = -\frac{1}{F} j^{\alpha,\mu} \partial_\mu G_\alpha + h.c. \tag{3.1}$$

Thus the gravitino couples the NLSP to its partner, in this case the gluon. F is related to the squark and slepton masses by

$$F \approx (4\pi/\alpha)^2 m_{\tilde{Q}}^2 \tag{3.2}$$

where α is the mediating gauge coupling constant. Assuming that α is between the ordinary fine structure constant and unity,

$$F \approx (10^2 to 10^6)\mathrm{m}_{\tilde{\mathrm{Q}}}^2. \tag{3.3}$$

The gluino decay width is then

$$\Gamma \approx m_{gluino}^5/F^2 \approx m_{gluino}(m_{gluino}/m_{squark})^4 \times (10^{-4} to 10^{-12}) \tag{3.4}$$

or, taking nominal values of 130 GeV and 130 MeV for the squark and gluino masses respectively,

$$\tau(gluino) \approx (10^{-7} to 10)\mathrm{s}. \tag{3.5}$$

In fact, since the gravitino couples particles to their superpartners and since the gluino lifetime is much longer than the hadronization time, the relevant decay is

$$R^0 \rightarrow f^0 + \tilde{G}. \tag{3.6}$$

Here f^0 denotes the glueball partner of R^0. Since with a light gluino we have an approximate supersymmetry in the gauge sector, f^0 and R^0 are expected to be approximately degenerate with R^0 only slightly heavier. Consequently the gravitino does not carry off enough energy to be caught by a missing energy trigger. In addition, the multi-pion decay of the glueball, coupled with a lifetime of up to $10s$ would make the state invisible to the current phase of KTev.

4 Conclusions

In the suggested scenario, all produced susy particles would decay strongly down to the R^0 which would then decay with a long lifetime and no appreciable missing energy to the lightest glueball. The UA1, Bebc, Helios, and stable particle search constraints in Figure 1 are then no longer operative. The CUSB constraint depends on a model for the gluinoball wave function at the origin and should perhaps not be regarded as a strict exclusion. The primary signature of SUSY production (e.g. charginos) at LEP II would be an excess in the visible energy cross section since standard model background would have appreciable energy loss to neutrinos from charm and bottom decays. Such an excess above the standard model monte carlos can in fact be perhaps seen in Figure 1 of the L3 note [48]. The light gluino predictions for the scaling violations at Fermilab would be preserved by this new decay scenario.

In the current model for gluino decay, one might also expect excess glueball production in Upsilon and B decays due to final states containing a gluino pair [7, 13]. This could be related to the observed anomalous $\eta\prime$ production in B decay [49] assuming the $\eta\prime$ has a significant glueball component.

In summary we feel that neither the weak hints in favor of a light gluino nor the counter-indications can be considered conclusive at this time and further experimental tests are needed. Further analysis of the LEP II data and the Fermilab Run II data along the lines we have suggested could provide the crucial tests for the existence of low mass SUSY particles.

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References

[1] P. Fayet, Nucl. Phys. **B90**, 104 (1975)

[2] G. Farrar and P. Fayet, Phys. Lett. **76B** ,575 (1978); G. Farrar and S. Weinberg, Phys. Rev. **D27**, 2732 (1983); G. Farrar, Phys. Lett. **B265**, 395 (1991); G. Farrar, Nucl. Phys. Proc. Suppl. **62**, 485 (1998)

[3] L. Clavelli, Phys. Rev. **D46**, 2112 (1992)

[4] J. Ellis, D. Nanopoulos, and G. Ross, Phys. Lett. **B305**, 375 (1993)

[5] L. Clavelli, P.W. Coulter, B. Fenyi, C. Hester, Peter Povinec, and K. Yuan, Phys. Lett. **B291**, 426 (1992)

[6] Thomas Hebbeker, Z. Phys. **C60**, 63 (1993)

[7] L. Clavelli, P.W. Coulter, and K. Yuan, Phys. Rev. **D47**, 1973 (1993)

[8] M. Jezabek and J.H. Kuhn, Phys. Lett. **B301**, 121 (1993)

[9] J. Blümlein and J. Botts, Phys. Lett. **B325**, 190 (1994)
R. Rückl and A. Vogt, Z. Phys. **C64**,431 (1994)

[10] A.L. Kagan, Phys. Rev. **D51**, 6196 (1995)

[11] L. Clavelli, Mod. Phys. Lett. **A10**, 949 (1995)

[12] G.R. Farrar and E.W. Kolb, Phys. Rev. **D53**, 2990 (1996)
D. Chung, G. Farrar, and E. Kolb, Phys. Rev. **D57**,4606 (1998)

[13] Peter Povinec, B. Fenyi, and L. Clavelli, Phys. Rev. **D53**, 4063 (1996)

[14] L. Roszkowski and M. Shifman, Phys. Rev. **D53**,404 (1996)

[15] L. Clavelli and I. Terekhov, Phys. Rev. Lett. **77**, 1941 (1996)

[16] L. Clavelli and I. Terekhov, Phys. Lett. **B429**, 51 (1998)

[17] L. Clavelli and Gary R. Goldstein Phys. Rev. **D58**, 095012 (1998)

[18] I. Antoniadis, J. Ellis, and D.V. Nanopoulos, Phys. Lett. **B262**, 109 (1991)

[19] L. Clavelli, P.W. Coulter, and Levan Surguladze, Phys. Rev. **D55**,4268 (1997)

[20] A.M. Badalian and V.L. Morgunov, hep-ph/9901430

[21] S. Alekhin, Phys. Rev. **D59**, 114016 (1999)

[22] S. Alekhin and A. Kataev, hep-ph/9812348, Phys. Lett. **B452**, 402 (1999)

[23] L. Clavelli and P.W. Coulter, Phys. Rev. **D51**, 1117 (1995)

[24] M. Shifman, hep-ph/9501222

[25] Delphi Collaboration, CERN-EP/99-44, Phys. Lett. **B456**, 322 (1999)

[26] L. Clavelli, P.W. Coulter, and Levan Surguladze, Mod. Phys. Lett. **A13**, 1987 (1998)

[27] Opal Collaboration Cern ppe/97-101, Eur. Phys. J. **C2**, 441 (1998)

[28] F. Abe et al., CDF Collaboration, Phys. Rev. Lett. **77**, 438 (1996)

[29] A. Bhatti, Fermilab-Conf-96/352-E, DPF conference, Minneapolis, 1996

[30] L. Clavelli, hep-ph/9812340, Fermilab Workshop on Supersymmetry/Higgs, (1998)

[31] S. Abachi et al., D0 Collaboration, Phys. Rev. Lett. **75**, 618 (1995)
D0 Collab., G. Blazey, Proceedings of the XXXI Rencontres de Moriond (March 1996).

[32] G. Farrar, hep-ph/9508291,292

[33] J. Adams et al, KTeV Collab., Phys. Rev. Lett. **79**, 4083 (1997)

[34] G. Farrar, hep-ph/9707467, La Thuile 1997; hep-ph/9710277, Nucl. Phys. Proc. Suppl. **62**, 485 (1998)

[35] R. Gustafson, C. Ayre, L. Jones, M. Longo and P. Ramana Murthy, Phys. Rev. Lett. **37**, 474 (1976)
R.H. Bernstein et al., Phys. Rev. Lett. **37** 3103, 1988

[36] S. Raby, hep-ph/9712254, Phys. Lett. **B422**, 158 (1998)

[37] H. Baer, K. Cheung, and J. Gunion, hep-ph/9806361, Phys. Rev. **D59**, 075002 (1999)

[38] I.F. Albuquerque et al, $E761$ Collab., Phys. Rev. Lett. **78**,3252 (1997)

[39] J. Hewett, T. Rizzo, M. Doncheski, hep-ph/9612377, Phys. Rev. **D56**, 5703 (1997)

[40] I. Terekhov, hep-ph/9702301, Phys. Lett. **B412**, 86 (1997)

[41] CUSB Collaboration, Phys. Lett. **138B**, 225 (1984)

[42] ARGUS Collaboration, Phys. Lett. **B199**, 291 (1987)

[43] C. Albajar et al., UA1 Collaboration Phys. Lett. **B198**, 261 (1987)

[44] T. Akesson et al., Helios Collaboration, Z. Phys. **C52**, 219 (1991)

[45] WA66 Bebc collaboration, A.M. Cooper-Sarkar et al., Phys. Lett. **160B**, 212 (1985)

[46] S. Dawson, E.Eichten, C. Quigg, Phys. Rev. **D31**, 1581 (1985)

[47] M. Carena, P.H. Chankowski, M. Olechowski, S. Pokorski, and C.E.M. Wagner, Nucl. Phys. **B491**, 103 (1997)

[48] The L3 Collaboration, L3 Note 2227, Submitted to the XXIX Int. Conference on High Energy Physics, Vancouver (1998)

[49] CLEO Collaboration, T.E. Browder et al. , hep-ex/9804018, Phys. Rev. Lett **81**, 1786 (1998).